eastern slopes (except in Vermont), and the eastern shores of the Great Lakes get more snow than the western.

Snow generally falls in connection with winter cyclones, for the cyclonic action and the effect of topography on the winds cause precipitation. As the northeast wind is both cold and damp over practically the whole eastern United States, it is the wind of the great snowstorms. The northwest wind, although cold, is generally dry and so brings, at most, only snow flurries except locally on a windward mountain slope or in the lee of the Great Lakes. In brief, the main factors which control snowfall are temperature, moisture in the air, exposure to moist winds, local topography, and the passage of winter cyclones.

REFERENCES AND NOTES.

(1) *See also* American Almanac for 1837, p. 169–185: "Notices of remarkably cold winters."

(2) Some other journals with less extensive records are:

Cleaveland, Parker. Results of meteorological observations made at Brunswick, Me., 1807 to 1857.

Caswell, Alexis. Results of meteorological observations made at Providence, R. I., from December, 1831, to May, 1860.

Hill, Leonard. Meteorological and chronological register, 1806 to 1869 at East Bridgewater, Mass. Plymouth, Mass. 1869.

(3) *See* J. P. Espy's reports in the Journal of the Franklin Institute, Philadelphia, 1839 to 1841.

(4) *See* Report of the **Smithsonian Institution** for 1855: Directions for meteorological observations, adopted by the Smithsonian Institution for the First-Class observers.

(5) **U. S. Weather Bureau.** Annual report of the Chief, 1891–92. Washington, 1893, p. 447.

(6) A history of meteorological observations in the United States is attempted by Marcus Benjamin in the work "The Smithsonian Institution, 1846–1896" (Washington, 1897) on pp. 647–678.

More complete details are given by various authors before the International Meteorological Congress, held at Chicago, Ill., August 21-24, 1893. (*See* U. S. Weather Bureau Bulletin 11. pp. 207–220, 232–302.)

(7) **Volney, C. F.** A view of the soil and climate of the United States of America. Translated from the French by C. B. Brown. Philadelphia, 1804.

(8) **Blodget, Lorin.** Climatology of the United States, and of the Temperate Latitudes of the North American continent. Embracing a full comparison of these with the climatology . . . of Europe and Asia. . . . Including a summary of the statistics of meteorological observations in the United States condensed from recent scientific and official publications. Philadelphia. 1857. xvi, [17]–536 p. 4°.

An appreciation of this monumental work will be found in the MONTHLY WEATHER REVIEW, January, 1914, **42:** 23–27.

(9) **U. S. Weather Bureau.** Rainfall and snow of the United States as compiled to the end of 1891, with annual, seasonal, monthly, and other charts. Text and Atlas. Washington. 1894. 80 p. 4°. Atlas: 23 charts, 18 x 24 inches.

This publication is reviewed in Amer. meteorol. jour., Boston, Mass., June, 1895, **12:** 71–2.

(10) **Henry, A. J.** *& others.* Climatology of the United States. Washington. 1906. 1012 p. 33 pl. 4°. (U. S. Weather Bureau bulletin "Q." W.B. no. 361.)

(11) *See* MONTHLY WEATHER REVIEW, Washington, June, 1914, **42:** 318–330.

(12) **U. S. Weather Bureau.** Summary of the climatological data for the United States by Sections 106 [sections]. Printed at various section centers. 1908–1912. var. pag. 4°. (Bulletin "W." W.B. no. 476.)

(13) Such an effect is clearly shown on the U. S. Weather Bureau "Snow and Ice Bulletin" for December 30, 1913.

(14) For a thorough study of the physical changes which take place in a snow-cover, *See* —

Jansson *&* **Westman, J.** Quelques recherches sur la couverture de neige. Bull., Geol. instit. of Upsala, 1901, No. 10, **5**, pt. 2, pp. 234–260.

(15) *See* MONTHLY WEATHER REVIEW, November, 1911, **39:** 1671; also Chart VIII in the REVIEW for November, 1911.

(16) The United States Forest Service official living at an altitude of 5,060 ft. on Mount Pisgah, N. C., 18 miles southwest of Asheville, N. C., recently told the writer that the snow accumulated on the ground, sometimes to a depth of 3 feet, and that in one night a snowfall of 27 inches occurred. The similarity between these extremes and those met in eastern Massachusetts, suggests that the average snowfall in the southern Appalachians may be about 50 inches annually.

(17) **Greely, Adolphus W.** American Weather. p. 162.

I.

THE RAINFALL OF THE NORTHEASTERN UNITED STATES.

By B. C. WALLIS, B. Sc. (ECONOMICS). F. R. G. S., F. S. S.

[Dated: North Finchley, England, Sept. 21, 1914.]

THE METHOD OF INVESTIGATION.

Probably the two most important considerations regarding the rainfall of any area are its total quantity and its distribution through the year. Attention is called in this paper to the second consideration, and an attempt has been made to measure the distribution by means of the statistical method of differences. The amount of rainfall which would be precipitated at a given place, upon the assumption that such rainfall were evenly distributed through the year, has been taken as a *norm*. This *norm* is obtained by dividing the total annual fall by 365, and by multiplying the quotient by 28, 30, and 31, respectively, to obtain the numbers which represent the norms for the month of February, and for the 30- and 31-day months. The value of the norm has been taken for each month for all places as 100, so that in the accompanying maps (figs. 2–5, 12–23),

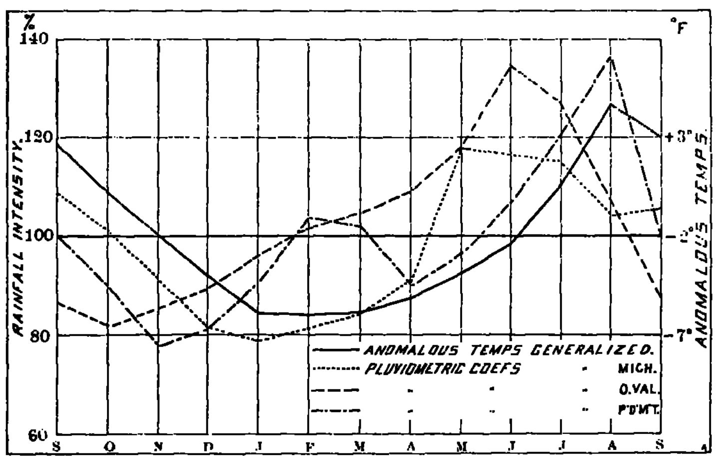


FIG. 1.—Annual march of pluviometric coefficients for Michigan, Ohio Valley, and the Piedmont compared with the annual march of the temperature anomalies for the northeastern United States.

the line which is marked 100 indicates that the rainfall at all places along that line is the norm for the month. Differences from the norm are expressed as percentages. Suppose the norm for a given place for January is 2½ inches, and the actual average rainfall at that place for January is 3 inches; then since, when 2½ = 100, 3 = 120, the difference for that place for January is 120, which implies that during January at that place the precipitation is 20 per cent above the norm; i. e., January is a relatively wet month.

The name "pluviometric coefficient" has been given to this quantitative expression by Dr. A. Angot, who is responsible for this application of the method of differences to rainfall studies. When pluviometric coefficients are indicated upon maps, upon the same principles as isohyets, the lines of equal departure from the rainfall norm have been called by the present writer "equipluves,"[1] using a Latin term for the sake of greater

[1] Mr. Ernest Gold (4) has pointed out that the "pluviometric coefficient" is "the ratio of the mean daily rainfall of a particular month to the mean daily rainfall of the whole year."

The term "isomer" has been suggested by Mr. C. Salter (4) in place of the term "equipluve" coined by Mr. Wallis. If the former term is used one should be careful to preface it with the word "rainfall" or "precipitation," since in itself "isomer" does not suggest a quality of rainfall. This disadvantage is absent from the term "equipluve."—[C. A., jr.]

distinctness. The accompanying maps show the equipluves for the several months for the northeastern United States.

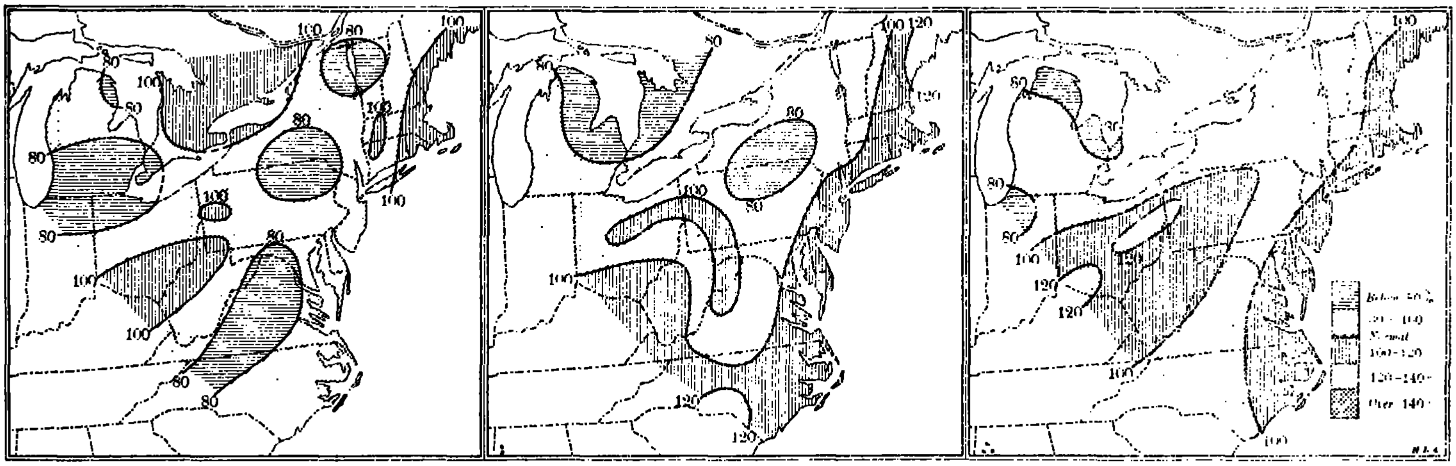
Equipluves in contrast with isohyets.—It has been laid down that monthly rainfall maps, where the rainfall is indicated by means of isohyets, are of little value unless (1) the observations have been taken over a long series of years, which should approximate to 50, and (2) observations for shorter periods than the main station period are carefully and laboriously reduced to the period of the main station observations. It is a matter of experience that, even when the monthly averages for rainfall have been carefully calculated, the occurrence of a sudden rain-splash [2] localized within a small area may disturb the general harmony and "run" of the isohyets.

The use of equipluves obviates these difficulties. The method of calculation adopted for the pluviometric coefficients smoothes out the accidental rain-splashes, and at the same time it tends to bring the values obtained during a dry series of years into closer harmony with the values obtained during a wet series of years. Consequently, the method of differences tends to allow the student to neglect all interpolative calculations in order to bring his values to the average required for a constant period of years.

[2] See an extract from H. R. Mill on p. 24, below.

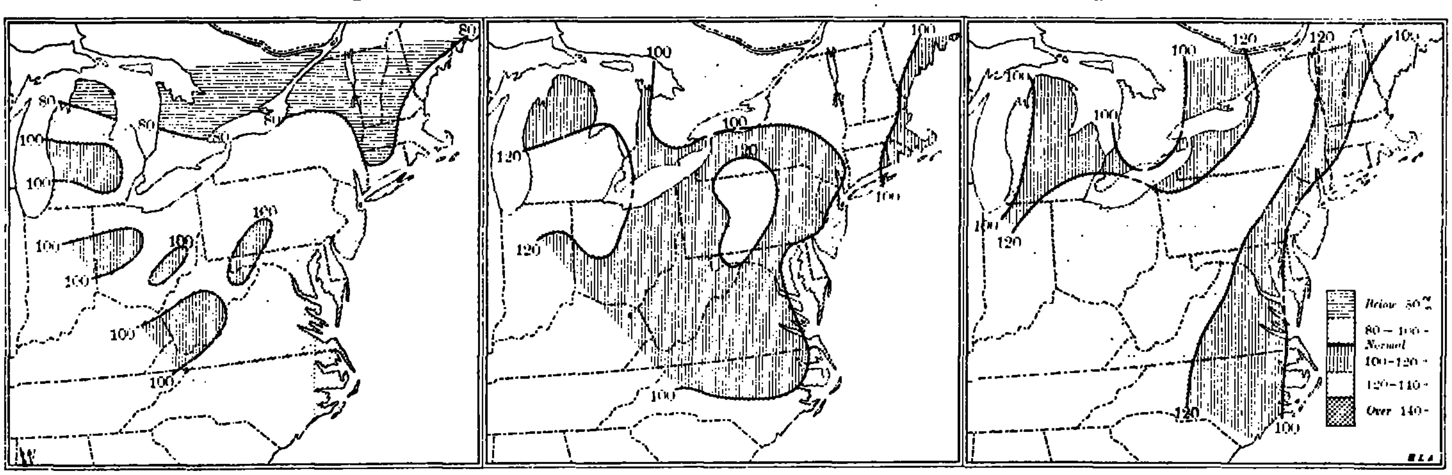
Suppose we divide the places of which there are rainfall records into three classes: (*a*) where the records have been kept for from 40 to 50 years, (*b*) where the records have been kept for from 20 to 40 years, and (*c*) where records have been kept for less than 20 years. When the maps are under construction, all stations in class (*a*) will be entered first, and the general run of the equipluves can then be determined; stations in class (*b*) will next be entered in all those cases where the values are in general harmony with the run of the equipluves; and stations in class (*c*) will be used to determine the run of the equipluves when other observations fail. In figures 2–5 accompanying this paper the "equipluves" are drawn at 20 per cent intervals, and it rarely happens that places in classes (*b*) and (*c*) differ by more than 10 per cent from the general average values of surrounding places. Consequently, in actual practice, most of the records can be utilized directly without resorting to methods of interpolation.

The utility of equipluves.—To express with some precision the aspect regarding rainfall which is under investigation the term "rainfall intensity" is used; and it may be urged that it is exactly rainfall intensity throughout the year which is the most important fact regarding rainfall, when once the average annual precipitation has been determined.



January. February. March.

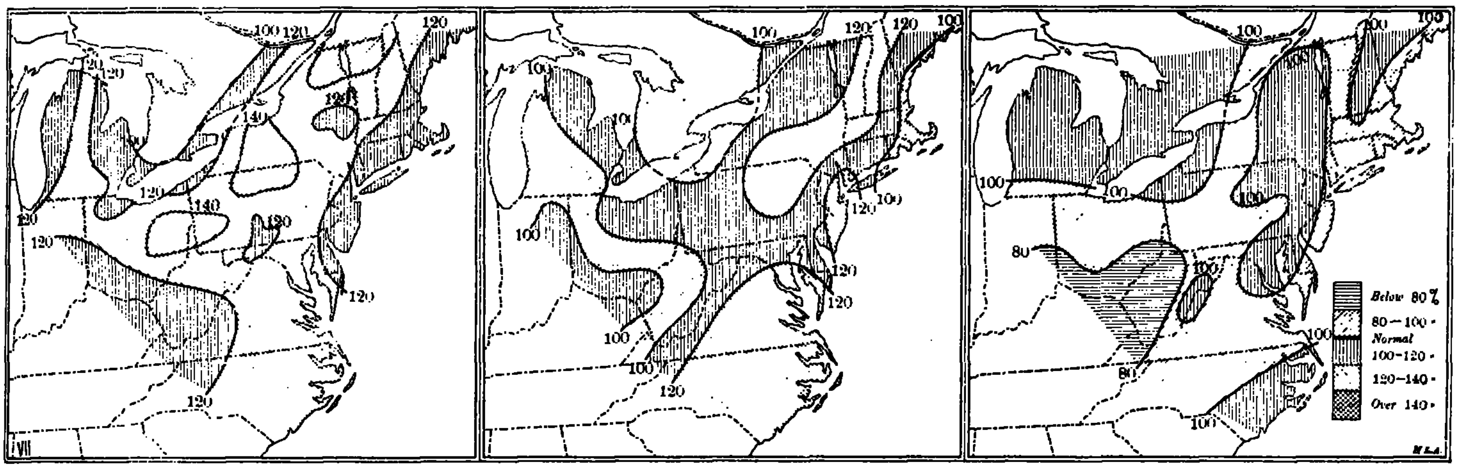
FIG. 2.—Equipluves for the northeastern United States for the months of January, February, and March.



April. May. June.

FIG. 3.—Equipluves for the northeastern United States for the months of April, May, and June.

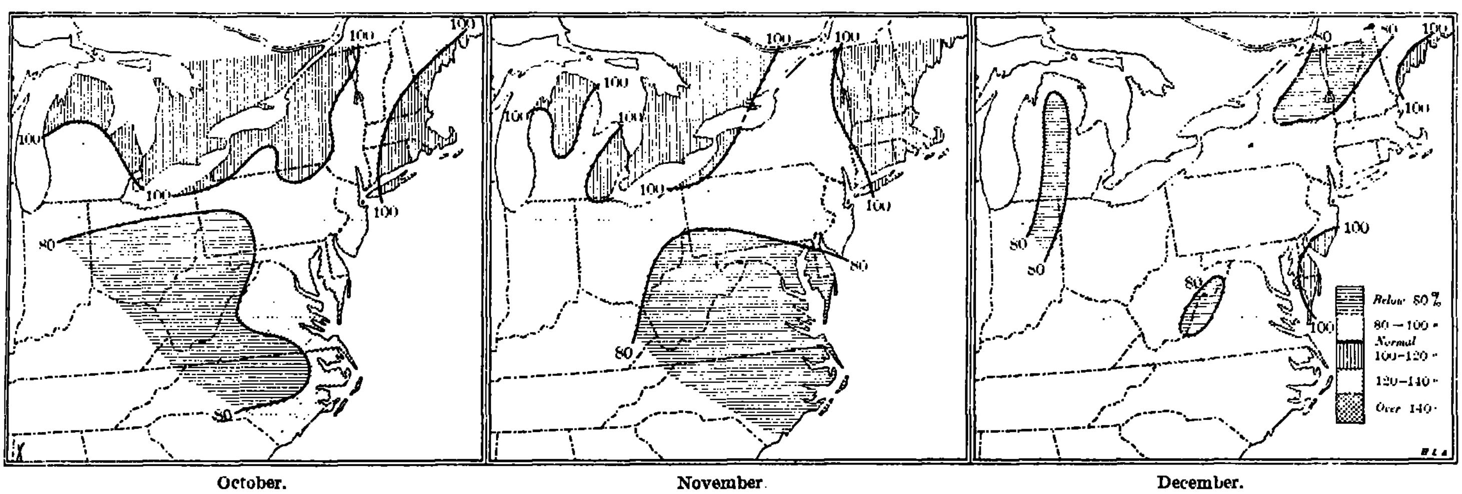
In another paper (1) the writer has studied the rainfall of the continent of Africa and finds the rainfall sequence throughout the year is related to the swing of the sun; also that the two portions of the continent north and south of the Equator present precisely similar general rainfall features. It has further been determined, in regard to the area of Africa where the actual annual total precipitation is heaviest, that the



July. August. September.

FIG. 4.—Equipluves for the northeastern United States for the months of July, August, and September.

rainfall intensity is of the same magnitude as in the desert where the actual precipitation is least. There is also, in all probability, little difference in magnitude and intensity between the rainfall of Africa between the desert areas and the "monsoon" rainfall of India.[3] In another paper (2) it has been demonstrated by the same methods that the continent of Australia presents similar features regarding its rainfall to those previously determined in the case of Africa. Now the question arises whether the intensity of the rainfall in areas



October. November. December.

FIG. 5.—Equipluves for the northeastern United States for the months of October, November, and December.

outside the limits of parallels 40°N and 40°S yields similar features; e. g. whether the pluviometric coefficients ever reach the magnitude of 300 and over; whether the rainfall intensity depends mainly upon the altitude of the sun.

In a third paper (3) it has been pointed out in the case of the district of the Southern Pennines in northern England that the intensity of the rainfall varies with the relief of the land. Wherever the land is lowland, the annual rainfall is relatively small and the highlands are relatively wet; but the wet districts have a greater rainfall intensity in winter than the dry districts, while the dry districts have a more intense rainfall in summer than the wet districts. Assuming that the sequence of rainfall intensity upon the lowlands is the average rainfall sequence due to the influence of the sun, then the effect of the hills is to superimpose upon the [average] rainfall [sequence] due to solar influences a great excess of rainfall upon the hills during the colder months. At the same time in this district of England the pluviometric coefficients have a maximum value of 150.

THE NORTHEASTERN UNITED STATES.

The accompanying maps (figs. 2–5) have been made from data published by the United States [Weather Bureau] in order to investigate the rainfall conditions upon the western margin of the Atlantic Ocean in relation to the results obtained for England and Africa. Figure 1 is based upon these maps. It gives the rainfall results in a general way and indicates that the rainfall on the whole "swings with the sun" and that the main effect of the uplands between the Ohio Valley and the Piedmont is to bring the rainfall sequence of the latter a month later in the year. The line marked "anomalous

[3] See an extract from the author's paper (1), reprinted on p. 24 below.

temperatures," which is based upon a series of maps published in paper (1) indicates for this portion of the United States the amount of variation, month by month, from the average temperature round the world in similar latitudes. This average temperature in similar latitudes measures air temperatures as a function of latitude; variations from average temperatures—i. e., anomalous temperatures—indicate the local temperature variations of the United States due to the effect of the sun upon the area of the northeastern United States. Consequently figure 1 shows that the rainfall of this area depends (1) upon the elevation of the sun, and (2) upon the world position of the area in particular reference to the swing of the sun. Figures 6 and 7 indicate the areas of differences in the driest and wettest periods, respectively, and give a spatial meaning to the facts shown in figure 1.

Consideration of the twelve monthly maps presented by figures 2, 3, 4, and 5 leads to a division of the northeastern United States into four rainfall regions—(1) the northeast corner which bears little relationship to the remainder of the area and can be omitted from further consideration; (2) the Lake region and Michigan on the north; (3) the Ohio Valley area in the middle, and (4) the Piedmont and the Coastal area on the southeast. It is convenient to begin the examination of the maps with the month of September. In that month the north (2) and the coast (4) are of average wetness, but the Ohio Valley (3) is relatively dry. In October the dryness is more extensive and reaches almost to the southeast [the South Atlantic] coast. In November the dry conditions have moved still farther eastward. In December the rainfall is very little removed from normal (100 per cent) everywhere. In January the Ohio Valley is wetter than the neighboring hills, and beyond the hills there is a still drier region. In February the coastal lands are wet and the north is dry. In March the Ohio Valley shows signs of greater wetness, which persists during April.

In May the north is the wettest region; this relative wetness spreads eastward by June and becomes more intense by July. In August the wetness has reached the coast. The maps, therefore, give a spatial significance to the conclusions previously stated, which may be generalized thus: A wave of dryness moves southeastward during the period when the temperature is falling, from September to the end of January, and a wave of wetness moves southeastward during the period when the temperature is rising, from May to August.

The rainfall of the northeastern United States is a function of its latitude and its position on the western margin of the Atlantic Ocean.

II.

THE DISTRIBUTION OF THE RAINFALL IN THE EASTERN UNITED STATES.

By B. C. WALLIS, B. Sc. (Economics), F. R. G. S., F. S. S.

[Dated: North Finchley, England, Nov. 24, 1914.]

In the preceding paper the sequence of the intensity of the rainfall was described in reference to the northeastern corner of the United States. This area includes the major portion of the industrial area of the United States and is a region of diverse farming operations; in the present communication the area which includes the cotton belt and the greater portion of the wheat belt has been added to the area previously described, and the rainfall of the whole area is now considered in a broader view and with less detail than was possible in regard to the northeast. The method of calculating pluviometric coefficients has already been described, so that it is possible to pass at once to the statement of the conclusions to be drawn from the accompanying maps and diagrams (figs. 6–23).

It should be noted, first, that the range of the rainfall intensity is much greater in the area now considered than in the northeast alone. The minimum value of the pluviometric coefficients is less than 33 and the maximum is between 200 and 233 which gives a range of 200 equivalent to one-sixth of the total annual precipitation. In the northeast corner the range extends from 70 to about 150, and is less than 100, i. e., less than the rainfall norm for one month. A general survey of the twelve monthly equipluve maps (figs. 12–23) at once forces the conclusion that, in general, the rainfall gradient is from northwest to southeast, for the majority of the equipluves run from northeast toward the southwest. This fact was suggested by the conclusions reached in the above communication.

The main features of the intensity of precipitation may now be considered month by month. In January (fig. 12) rainfall slightly above the norm occurs in the valleys of the lower Mississippi and the Ohio; to the southeast and to the northwest the intensity of rainfall diminishes. In February the area of rainfall above the norm has extended toward the coast and in Alabama and Georgia the rainfall is most intense; elsewhere there is little change from January. In March, except for an increased intensity in the Dakotas and along the coastal lowlands near Chesapeake Bay there is slight change from February.

In April, west of the Mississippi, the rainfall is above the norm, and the area east of that river tends to be drier. In May there is a marked increase in the intensity of the rainfall especially in Oklahoma and South Dakota; in general, the intensity of the rainfall increases with the distance from Florida. In June the southeast coast States and the northwest States show a marked increase in intensity; from the Dakotas to Kansas, the rainfall is at the maximum for the whole area, the fall in June being equal to twice the norm. Alabama has the least intense rainfall and the month in general is the exact opposite of January and February.

In July the whole intensity seems to have moved toward the northwest, the coasts are wetter and the northeast is drier than in June. In Belt I (fig. 8 and 9) the rainfall intensity "swings with the sun," and the farther away the land lies from the ocean, the more precisely is this fact true. About the seasons of the equinoxes the rainfall is the norm, at midwinter low, and at midsummer it is high; the pluviometric range is very large. In Belt II (fig. 8 and 10), in general, the pluviometric range is least; the most striking feature of the diagram is the way in which the graphs interlace. On a very small scale the rainfall of this belt varies with the "swing of the sun." The whole of this belt is marked by a comparative steadiness of the precipitation throughout the year; it forms a striking illustration of the phrase "rainfall at all seasons." In Belt III (fig. 8 and 11), the pluviometric range is intermediate between those in the other two belts and the distribution of the rain is unequal. From November to July, i. e., about two-thirds of the year, the rainfall intensity increases by two stages which are separated by a slight fall near the spring equinox. The intensity drops suddenly from August to November.